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# Wind tunnel tests of a free yawing downwind wind turbine

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## Abstract

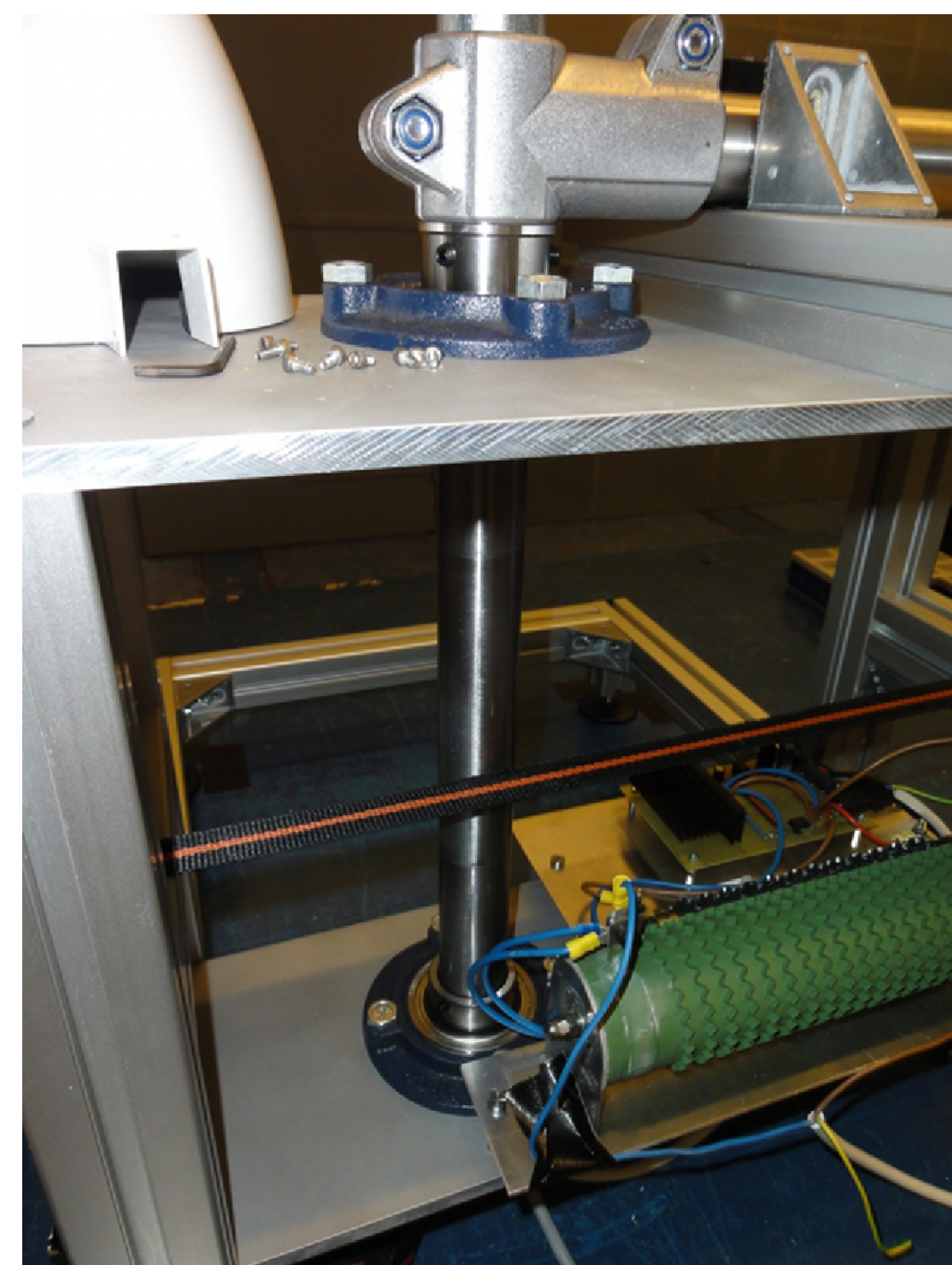
During February and April 2012 a series of wind tunnel tests were performed at the TU Delft Open Jet Facility (OJF) with a three bladed downwind wind turbine and a rotor radius of 0.8 meters. The setup includes an off the shelf three bladed hub, nacelle and generator on which relatively flexible blades are mounted. The tower support structure has free yawing capabilities provided at the tower base. A short overview on the technical details of the experiment is provided as well as a brief summary of the design process. The discussed test cases show that the turbine is stable while operating in free yawing conditions. Further, the effect of the tower shadow passage on the blade flapwise strain measurement is evaluated. Finally, data from the experiment is compared with preliminary simulations using DTU Wind Energy's aeroelastic simulation program HAWC2.

## Key characteristics of the experiment

- Off the shelf small wind turbine with aluminium cast nacelle, standard 300W generator, hub disc with three mounting points for the blades.
- Stiff and flexible blade sets made from PVC foam with inner glass fibre beam. Blade length is 55 cm.
- The tower base is suspended on two bearings, allowing the complete tower to yaw. The nacelle is fixed to the tower top.
- Blade root airfoil: NREL S823 (21% thickness)
- Blade tip airfoil: NREL S822 (16% thickness)
- Aerodynamic coefficients taken from the UIUC airfoil wind tunnel test database for a Reynolds number of 100,000.
- In free yawing mode the yaw angle range is approximately -35 to 35 degrees. The yaw angle can be locked or manually controlled in from the control room with ropes.
- The generator is connected to a variable electrical load (resistance) for limited torque variability. No active rotor speed control was pursued during the experiments.
- Due to the limit rotor torque control two operating conditions exist: low RPM's for a deeply stalled rotor, and high RPM's near optimal tip speed ratio's.
- Strain gauges on the tower base in for-aft and side-side directions.
- Strain gauges on two blades at the root and 30% radius positions. Wireless transmission of data to acquisition pc.
- Laser distance meter to measure the yaw angle.
- Wind speed, temperature and static pressure measurements.

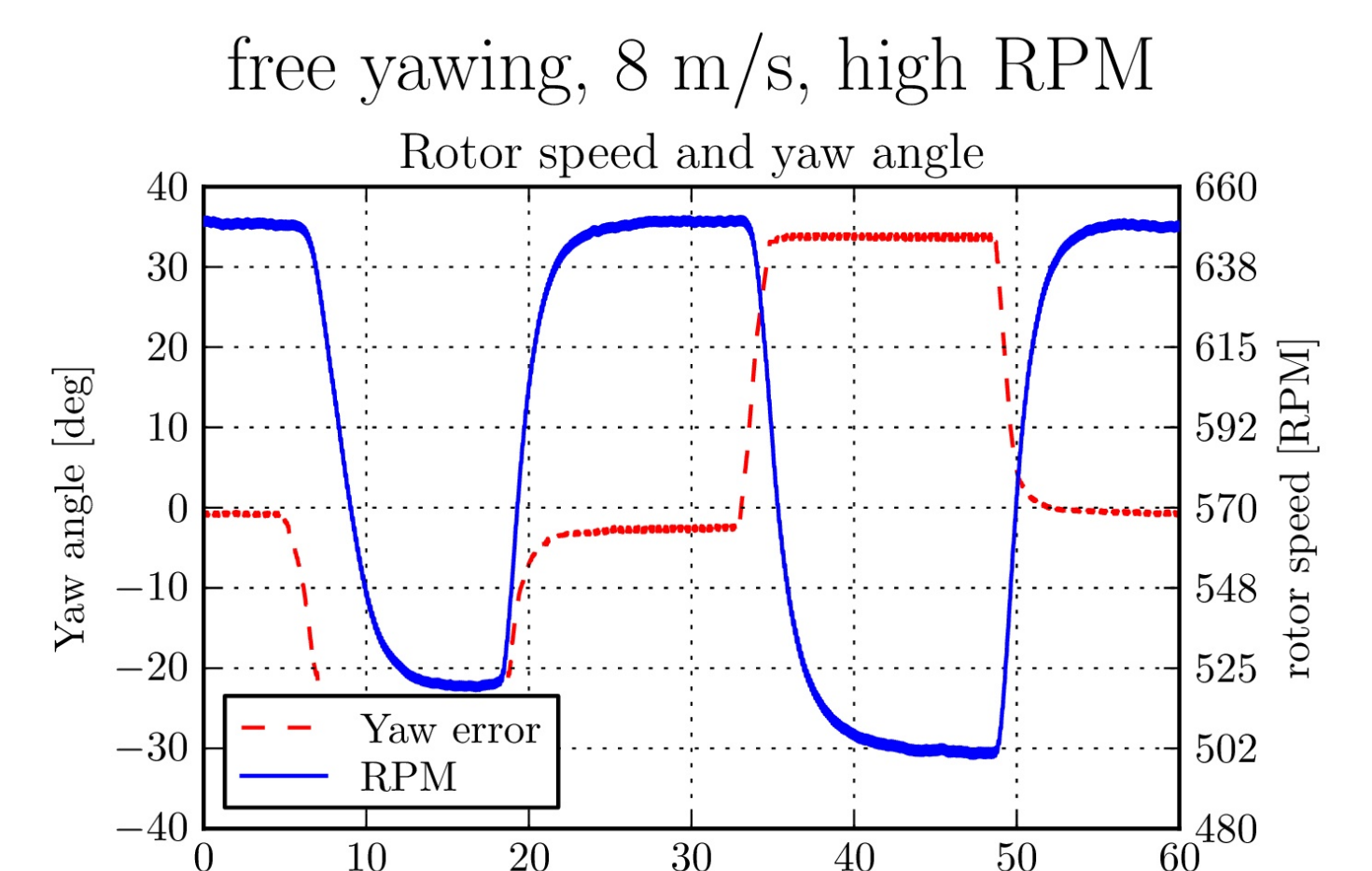
## Tower shadow passage and blade strains

The experiments show that the blades passing the tower shadow on this downwind turbine have a significant effect on the blade loading.

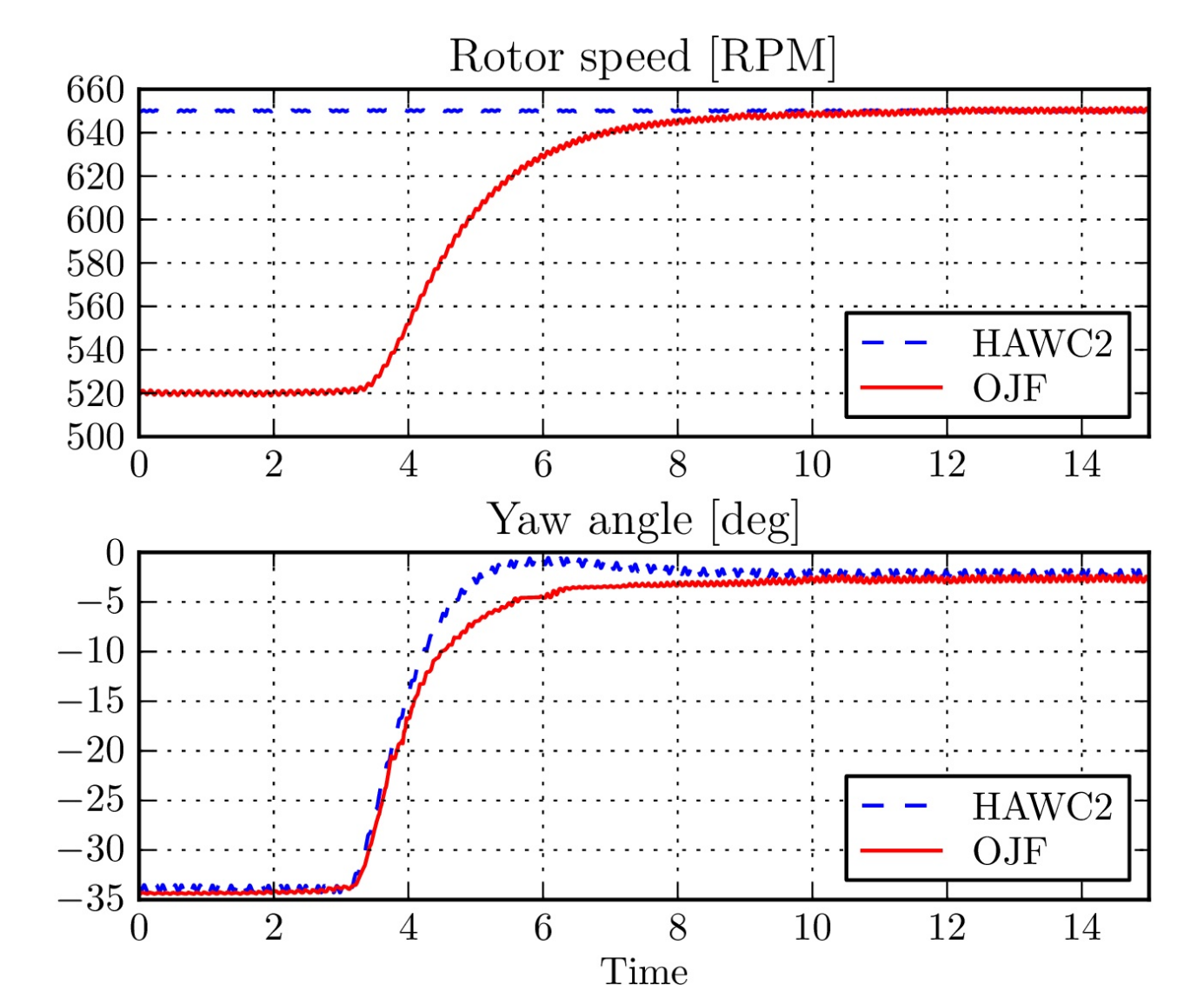


## Free yaw stability and HAWC2 comparison

The figure on the right illustrates the stability of the yawing as measured in the OJF wind tunnel. The yaw angle is forced to either side (35 degrees) and released again. The yaw error recovery is almost instantaneous and there is no sign of any oscillation.



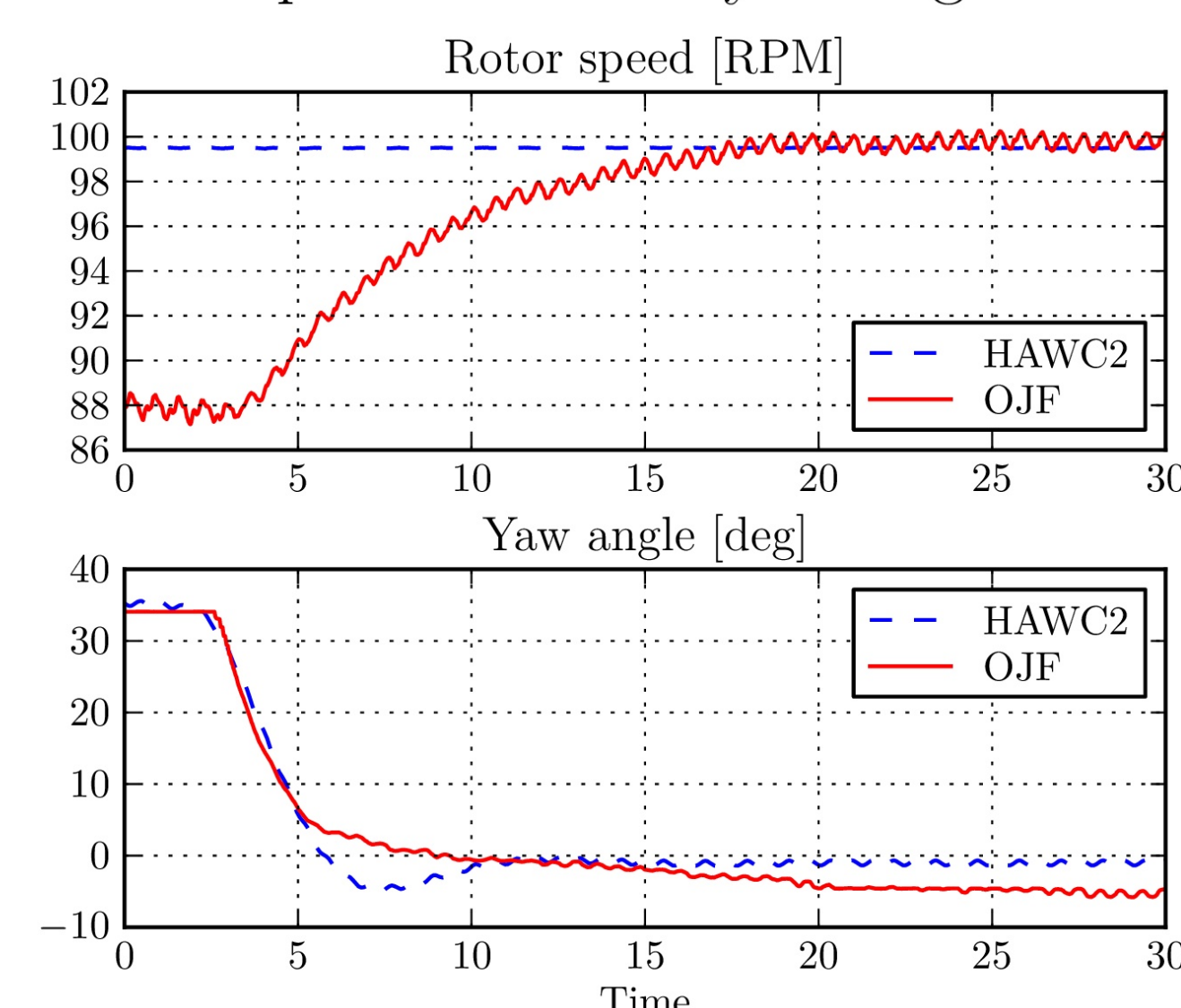
8 m/s, high RPM, free yawing



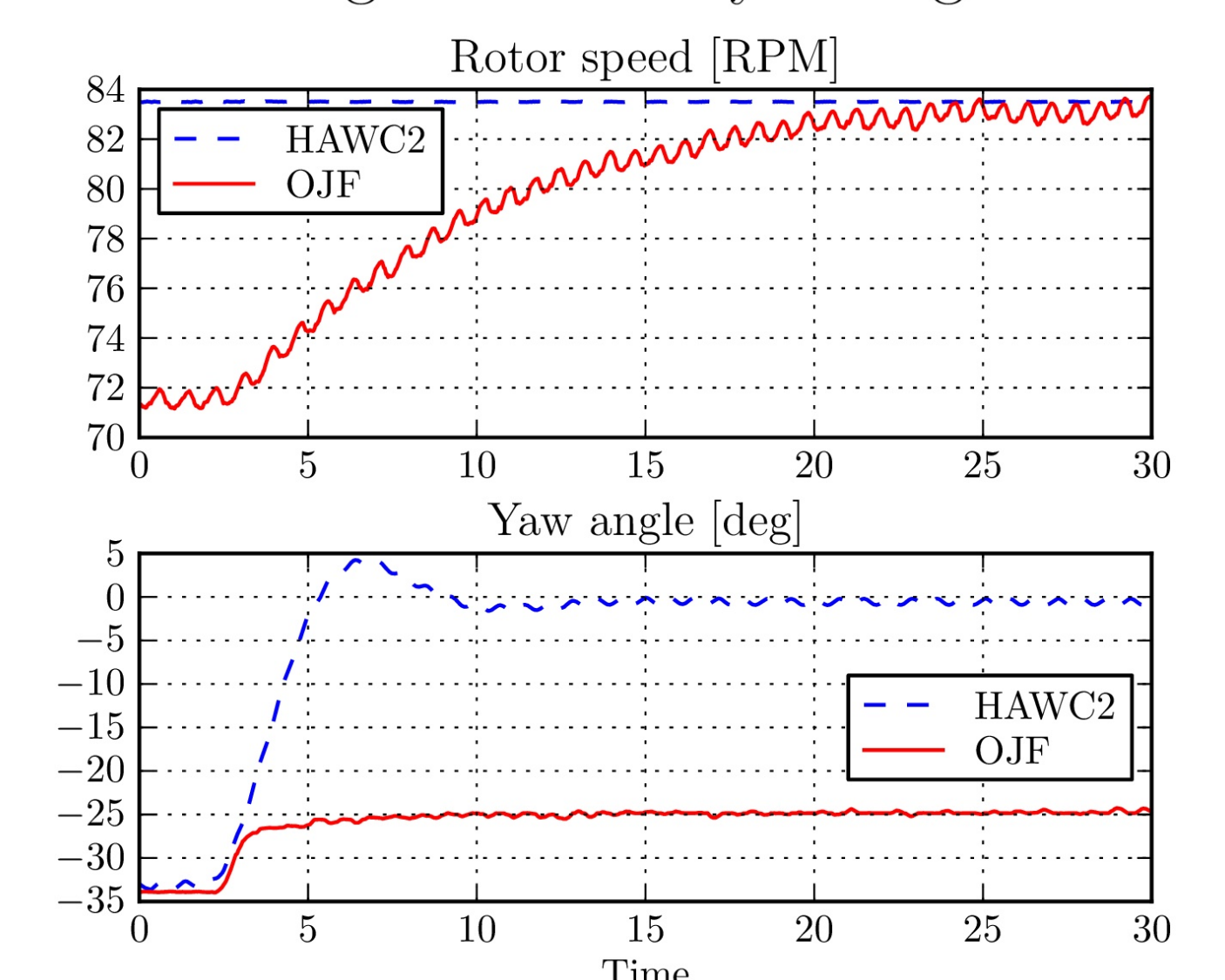
When comparing with HAWC2 simulations we see a similar result (see figure on the right): the yaw angle recovers very quickly. Note that the simulations predict a slight overshoot not seen in the wind tunnel.

In deep stall conditions, an asymmetric response on the yaw angle is observed which depends on the initial forced yaw error (see figures below). This asymmetry is not seen in the simulations.

8 m/s, low RPM, free yawing, positive forced yaw angle



8 m/s, low RPM, free yawing, negative forced yaw angle



## Conclusions

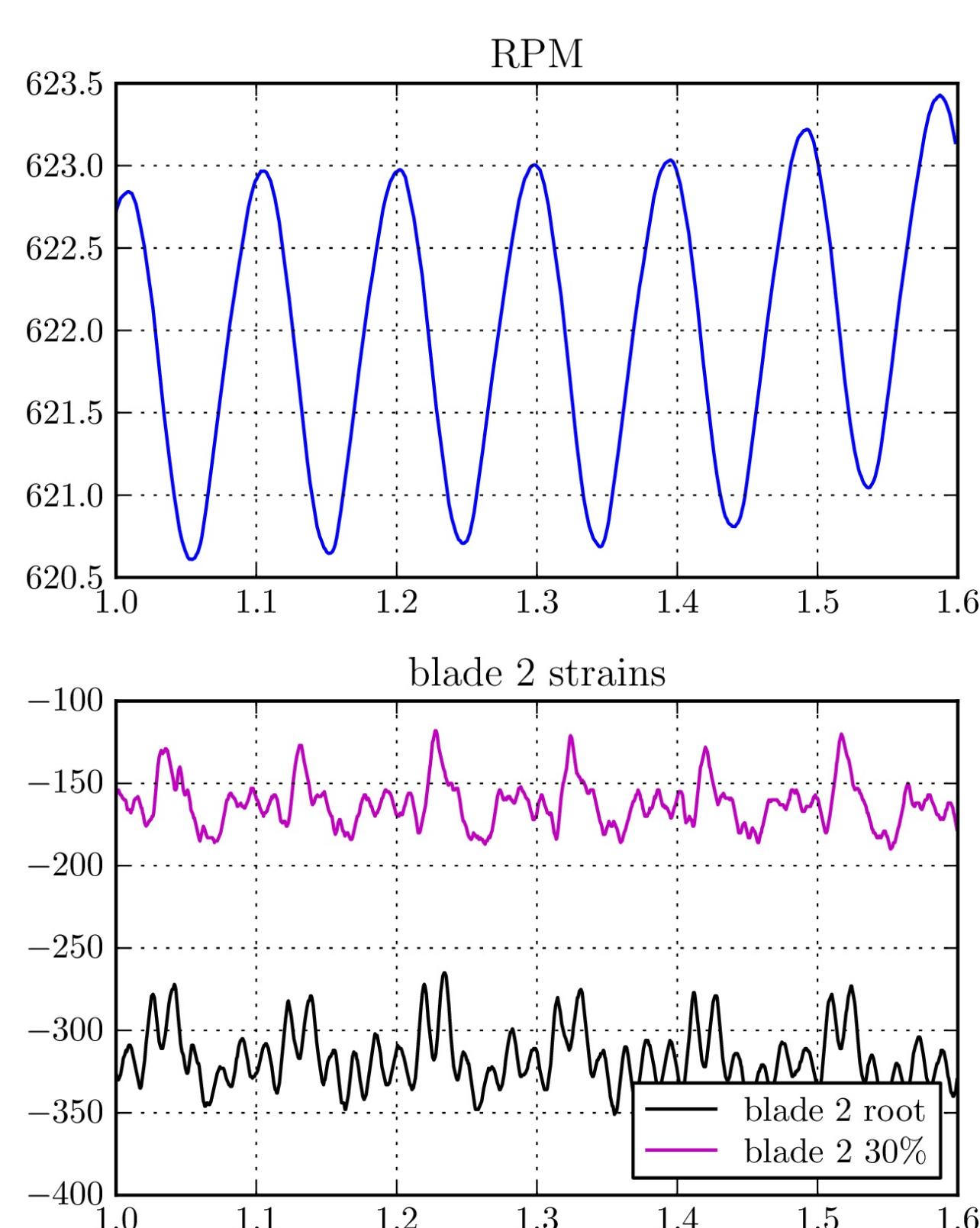
This paper discussed the work in progress of wind tunnel test results analysis and comparison with HAWC2 simulations. Conclusions so far state that:

- A three bladed downwind wind turbine is stable in yaw for the considered test cases.
- When the rotor is in deep stall the free yawing cases are stable, but they operate under a constant yaw error. Simulations do not show the same behaviour and this subject requires further investigation.
- As expected, tower shadow passage has a significant effect on blade loading. When comparing low and high rotational speeds, the load amplitudes introduced by the tower shadow are smaller for the latter.
- The HAWC2 simulations show a similar stability behaviour when compared to the OJF data. However, in deep stall conditions at low rotational speeds the experiment operates under a constant yawing error. The latter is not observed in the simulations.
- Free yawing dynamics shows more damping in the experimental results compared to the HAWC2 simulations.

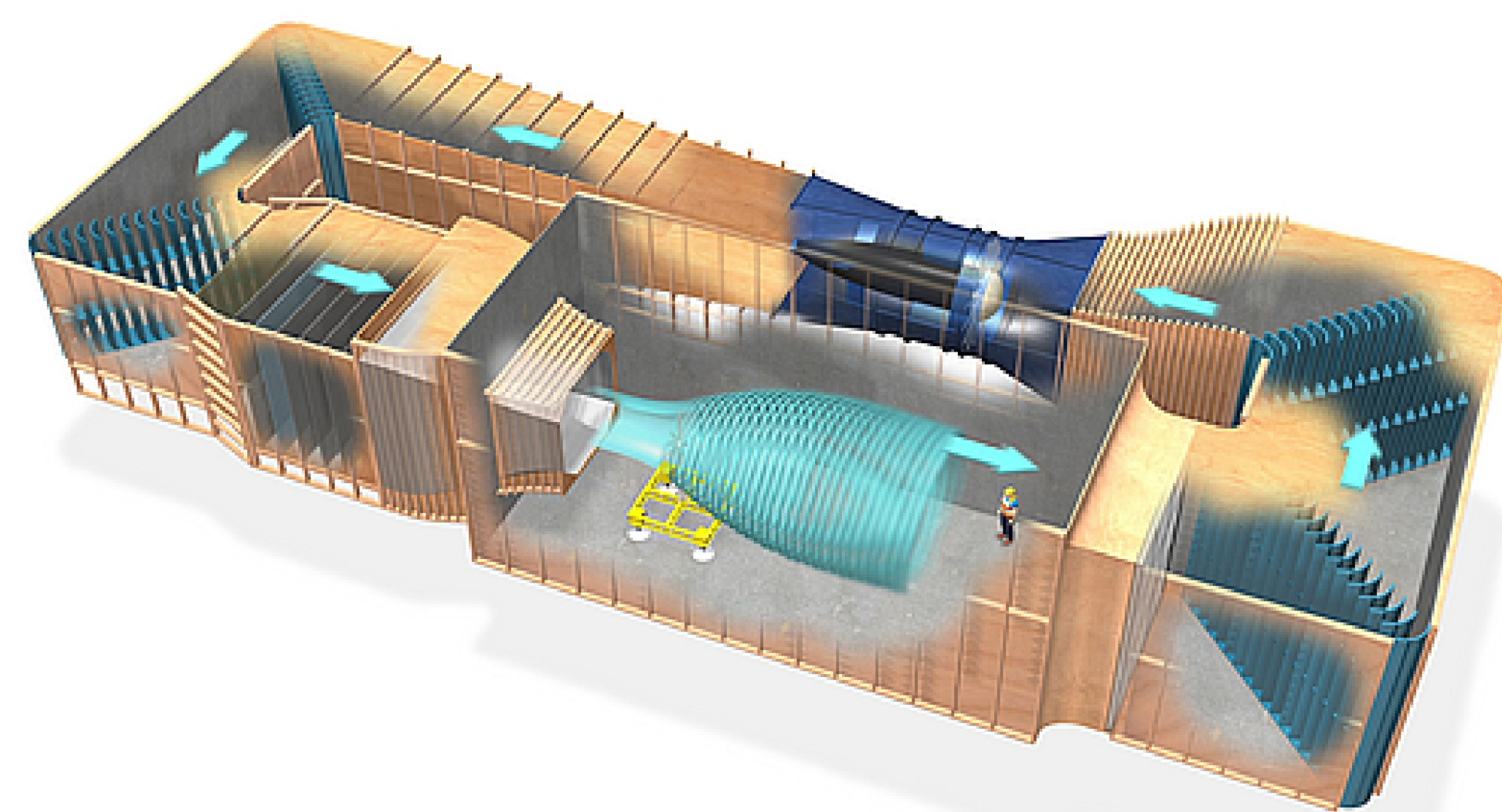
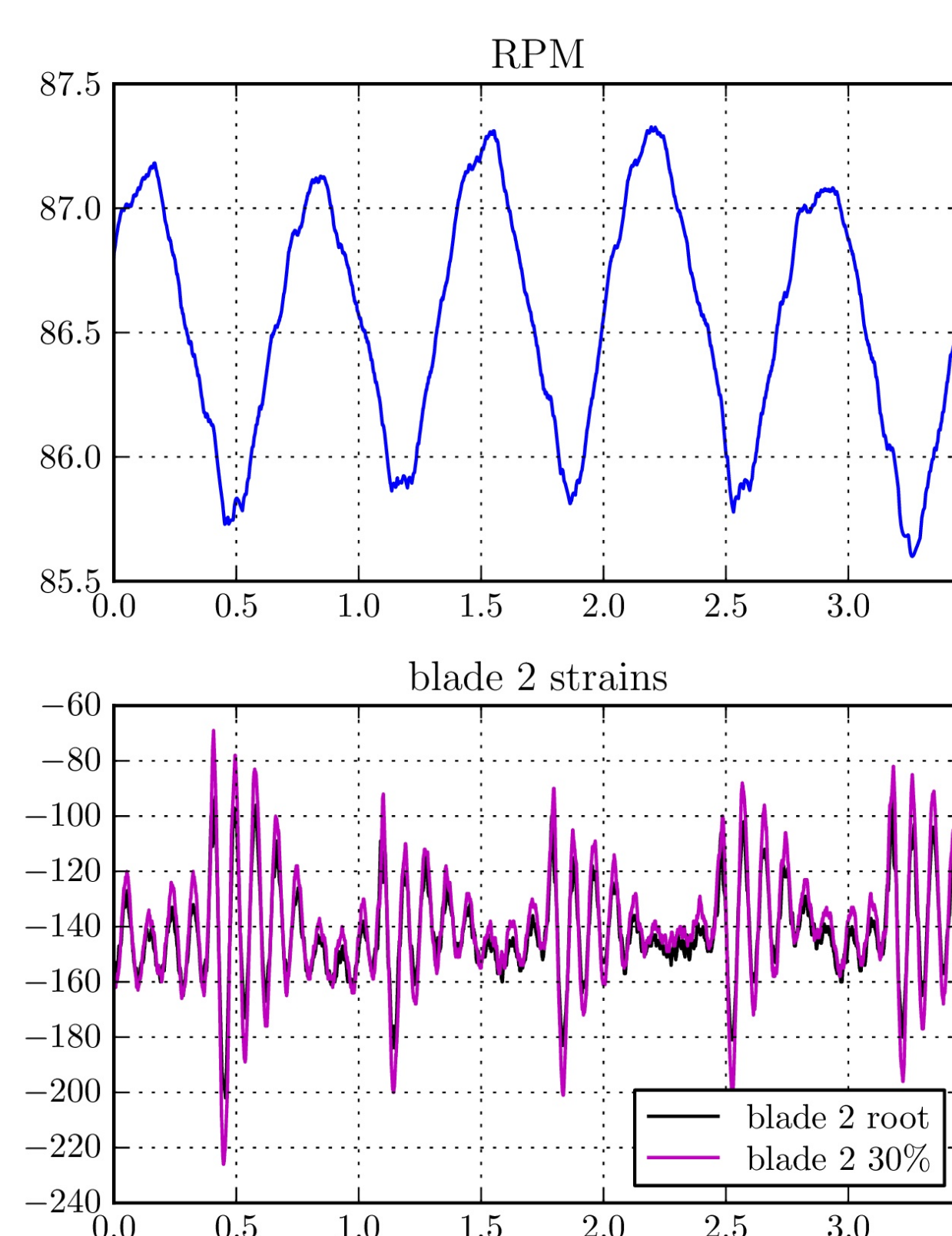
## Acknowledgements

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fixed yaw, 9 m/s high RPM



fixed yaw, 9 m/s, low RPM



Schematic overview of the OJF wind tunnel at the TU Delft